Predetection Telemetry Analog Recording and Playback for Pioneer Venus 1978

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Equipment and techniques have been developed to assure the DSN will meet the 1.5-dB degradation commitment to the mission for data recovery during the mission probes encounter.

I. Introduction

The Pioneer-Venus 1978 (PV-78) Mission has a requirement for predetection telemetry analog recordings of the received signals from each of the four probes during the active probe mission phase (Ref. 1). The DSN has committed to record and play back these data with no more than 1.5-dB signal-to-noise ratio (SNR) degradation due to the recording and playback processes. The recordings are to be made at DSS 14 and 43 and the playback is to be done at Compatibility Test Area (CTA) 21.

In order to insure meeting the DSN commitment, new equipment had to be incorporated into the stations and new techniques and procedures had to be developed. This article discusses the considerations involved for assurance that the commitment would be met.

II. Basic Concept

The basic concept of predetection recording and playback is shown in the simplified diagram of Fig. 1. The incoming S-band telemetry signal is heterodyned to a frequency low enough to permit recording on the analog recorder (for PV-78, less than 300 kHz). On playback, this signal is upconverted to an S-band frequency and injected into a standard DSN closed-loop receiver (CLR), and the data is then processed in the conventional manner.

Each probe has its own dedicated receiver and each receiver output has a dedicated track on the recorder. Playback can be accomplished on only one probe at a time due to upconverter limitations.

III. SNR Degradation Causes

There are three primary causes for SNR degradation in this basic concept:

(1) Phase nonlinearities.

(2) Additive noise.

(3) Analog recorder perturbations.

A secondary cause is signal suppression due to amplitude limiting (saturation) occurring in any of the amplifiers. This cause is eliminated simply by controlling the total gain and the gain distribution.

IV. Phase Nonlinearities

The degradation of SNR due to a reduction in signal power caused by phase nonlinearities can be determined from the following equations (Eqs. 9 and 11 of Ref. 2):

$$S = \frac{1}{4} \sum_{n=1}^{N} \left(a_n^2 \cos \theta_n^u + a_n^2 \cos \theta_n^L \right) \tag{1}$$

$$p = 10 \log_{10} S \tag{2}$$

where

S = signal power, relative to unity

$a_n = \frac{4}{\pi n}$

n = subcarrier harmonic number (for square wave modulation, n = odd numbers)

θ^u, θ^L = deviation of upper and lower sidebands from a linear phase relationship

p = reduction of signal power in dB

If $\theta^u = \theta^L = \theta$ for all n, Eq. (1) becomes

$$S = \frac{8 \cos \theta}{\pi^2} \sum_{n=1}^{N} \frac{1}{n^2}$$

from which

$$P = 10 \log_{10} \left(\frac{8}{\pi^2} \sum_{n=1}^{N} \frac{1}{n^2} \right) + 10 \log_{10} (\cos \theta) \tag{3}$$

Thus the additional signal power reduction due to fixed deviation from a linear phase relationship is

$$P_a = 10 \log_{10} (\cos \theta), \text{ dB} \tag{4}$$

which of course translates directly into SNR degradation. To minimize this degradation, the open-loop receiver phase response is linear to within 2 deg over the 300-kHz passband of the receiver, for a negligible SNR degradation of 0.003 dB.

At a tape recorder speed of 76.20 cm/sec (30 in./sec), the recorder 3-dB amplitude response is from 400 Hz to 500 kHz and its linear phase response is from approximately 1.0 to 300 kHz. The group delay variation of the analog recorder is specified at 1.0 μsec peak over a 400-kHz passband, which is equivalent to a deviation from a linear phase response of 2 deg in 5 kHz (assuming a constant slope to the group delay variation). This also results in a SNR degradation of 0.003 dB. Since the total required bandwidth for any of the probes never exceeds 240 kHz (Ref. 1), bandwidth limitations and phase nonlinearities problems are negligible.

V. Additive Noise

Additive noise (for purposes of this discussion) is simply noise that is added as a result of the signal processing employed specifically for recording and playback purposes. The open-loop receiver (to be described in a later DSN Progress Report) consists of front-end and first intermediate frequency (IF) amplifier designs similar to those of the existing closed-loop receivers, thus resulting in no difference in signal processing to this point. The second IF covers the frequency range of 15. to 300 kHz and presents the first additive noise problem due to "image noise rejection" difficulties. This problem is solved through the use of a single-sideband mixer in which the image noise is rejected by a factor of 1000 (30 dB). Thus, the additive noise power due to image noise is 0.1% relative to the desired passband noise for an SNR degradation of 0.004 dB.

The second additive noise source is the analog tape recorder. The H-96 recorder performance specification is such that for a 300-kHz bandwidth, the output SNR is $\geqslant$22 dB for an input signal level of +10 dBm (50 ohms). This additive noise ($\leqslant$0.62%) results in an SNR degradation of $\leqslant$0.027 dB.

The upconverter is the third additive noise source. It is specified to operate at a signal input level of +10 dBm (50 ohms). With an effective noise temperature of 30,000 kelvins, the additive noise power is −99 dBm, resulting in negligible degradation.

The final additive noise source is the closed-loop receiver. For PV-78 the tape playbacks will be done at CTA 21 where the system operating temperature is approximately 1000 kelvins. In a bandwidth of 300 kHz at 1000 kelvins, the input noise level of the closed-loop receiver is −114 dBm. To limit the SNR degradation to $\leqslant$0.04 dB (1%), the upconverted noise level should be $\geqslant$94 dBm.

The total noise then at the CLR input becomes

$$P_{NT} = (1.001)(1.006)(1.01) N_1 = 1.017 \, P_{N1}$$

where P_{N1} = OLR effective noise input power level from which the additive noise is 0.017 N_1 for a degradation of 0.07 dB.

VI. Analog Recorder Perturbation

Velocity perturbations of the analog recorder can result in SNR degradations. These perturbations are generally referred to as *flutter, jitter,* and *time base error* and are defined as follows:

Flutter: The instantaneous "short term" speed deviation from the "long term" average speed of the recorder. It is usually expressed in peak-to-peak percentage of velocity deviation.

Jitter: The maximum peak-to-peak spacing change in time of a series of pulses of a given nominal spacing. Varying frequencies of flutter result in varying amounts of jitter.

Time Base Error (TBE): The error in the spacing in time of any two points on the tape as compared with the actual spacing that existed during the recording. Time-base-error is related to flutter and can be expressed mathematically as

$$TBE = \int_0^t A \cos \omega t \, dt$$

$$= \frac{1}{2\pi} \frac{A}{f} \sin \omega t$$

where A = peak flutter and f = flutter frequency in cycles per second. The impact of the perturbations on SNR can only be measured indirectly by comparing real-time SNR with that SNR achieved during tape playback.

With the advent of the newer generation analog recorders (i.e., Honeywell H-96, Ampex FR-2000, Ampex FR-3010) employing low inertia capstans and speed-lock servo loops, analog recorder perturbations cause about 0.5 dB SNR degradation (for PV-78 data rates) when operated at tape speeds of 38.10 cm/sec (15 in./sec) or faster. For PV-78, the Honeywell H-96 recorders are being installed at DSS 14 and 43 for recording and CTA 21 for playback. Tape speed will be 76.20 cm/sec (30 in./sec).

A field demonstration (Ref. 3) conducted on Pioneer 11 in June of 1975 demonstrated that degradation due to analog recorder perturbations should be well below 1.0 dB for the PV-78 mission. In fact, if 0.1 dB degradation is assumed for additive noise (which is reasonable, based on above), the field demonstration indicates that recorder perturbations contributions are about 0.5 dB. Recent PV-78 compatibility testing (Nov. 1977) conducted at CTA 21 showed total SNR degradation to average about 0.5 dB, indicating recorder perturbations contribution to be about 0.4 dB. Other testing conducted at CTA 21 in the past confirms the above findings (these tests will be the subject of a later DSN Progress Report).

VII. Gain Requirements

Using the relationships

$$P_S = P_C + P_D \ll P_{N1}$$

where

P_S = total received signal power

P_C = carrier power

P_D = data power

P_{N1} = OLR input noise level, (KT_1B_1)

K = Boltzmann's constant, -198.6 dBm

T_1 = OLR system temperature

B_1 = OLR noise bandwidth

the gain requirements can be determined once an acceptable level of degradation due to additive noise is established. Selecting the additive noise degradation at ≤0.07 dB, the following equations can be written:

$$P_{NT} = GP_{N1} + P_{NA} \leqslant 1.017 \, GP_{N1} \tag{5}$$

$$\frac{P_{NA}}{GP_{N1}} \leqslant 0.017$$

where

G = total gain from OLR in to CLR in

P_{NA} = total additive noise power

From Figure 1

$$G = G_1 G_2 G_3$$

$$P_{NA} = G_2 G_3 P_{N2} + G_3 P_{N3} + P_{N4}$$

from which

$$\frac{P_{NA}}{GP_{N1}} \leqslant \frac{P_{N2}}{G_1 P_{N1}} + \frac{P_{N3}}{G_1 G_2 P_{N1}} + \frac{P_{N4}}{G_1 G_2 G_3 PN_1}$$

From the additive noise discussion

$$P_{N3} \ll G_1 G_2 P_{N1}$$

$$G_2 = 1.0$$

$$\frac{P_{N2}}{G_1 P_{N1}} = 0.0062$$

Now,

$$P_{N1} = KT_1 B_1$$

$$P_{N4} = KT_4 B_4$$

where

$$B_1 = B_4 \text{ (our case)}$$

$$0.017 \geqslant .0062 + \frac{T_4}{GT_1}$$

$$\frac{GT_1}{T_4} \geqslant 92.6$$

or

$$G \geqslant 19.7 + 10 \log T_4 - 10 \log T_1, \text{ dB} \qquad (6)$$

The minimum required gain is when Eq. (6) is equal. The maximum gain allowable is a function of amplitude limiting and is determined as follows:

$$P_{N\ MAX} = G_{MAX} P_{N1} + P_{NA}$$

$$G_{MAX} = \frac{P_{N\ MAX} - P_{NA}}{P_{N1}} \approx \frac{P_{N\ MAX}}{P_{N1}} = \frac{P_{N\ MAX}}{KT_1 B_1}$$

Thus

$$G_{MAX} = P_{N\ MAX}(\text{dBm}) + 198.6 - 10 \log T_1 - 10 \log B_1, \text{ dB} \qquad (7)$$

and

$$G_{MIN} = 19.7 + 10 \log T_4 - 10 \log T_1 \text{ db} \qquad (8)$$

For recording at a 64-meter station and playing back at CTA 21:

$$P_{N\ MAX} = -80 \text{ dBm}$$

$$T_1 = 25 \text{ kelvins}$$

$$B_1 = 300 \text{ kHz}$$

$$T_4 = 1000 \text{ kelvins}$$

from which

$$G_{MAX} = 50 \text{ dB}$$

$$G_{MIN} = 36 \text{ dB}$$

Table 1 tabulates the gain limits for various recording and playback station combinations. Examination of the table shows that playback at the 64-m stations at a system temperature of 300 kelvins is not feasible due to noise limiting under minimum gain requirements.

VIII. Gain Settings

The method of establishing the correct playback gain setting is to "lock" the CLR to the S-band carrier signal and adjust the input level until the automatic gain control voltage indicates the correct gain has been achieved. This method is based on knowing what the original incoming signal carrier level was during the recording period. This information is available from the mission predicts or from the CLR that was tracking in real-time.

IX. Summary

Predetection telemetry recording and playback capability is being implemented in the DSN to meet PV-78 mission requirements. Test data, along with theoretical considerations, gives assurance that the data degradation commitment of 1.5 dB will be met, and it is anticipated that in actual performance the design goal of 1.0 dB will be met.

Operation of the equipments is straightforward and can be summarized as follows:

Recording

1. Adjust OLR output level to +10 dBm
2. Adjust OLR frequency to predicts
3. Record OLR output at 76.2 cm/sec

Playback

1. Set UC output level to maximum
2. Lock the CLR to the carrier signal
3. Adjust the UC output level to within the gain limits of Table 1.
4. Lock the SDA, SSA and TPA per conventional procedures and process data.

The major technical problems requiring solving were the elimination of "image noise" in the OLR and the reduction of analog recorder instabilities. These were solved through the use of single-sideband mixing techniques and the use of newer generation analog recorders.

Acknowledgment

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References

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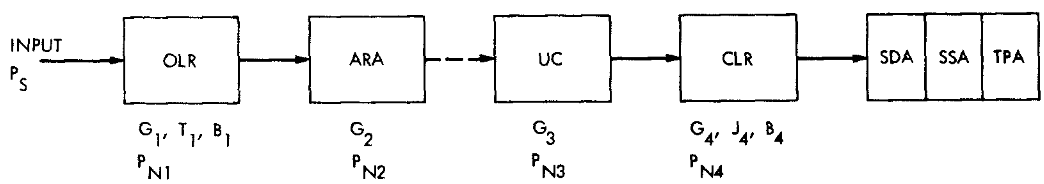
Table 1. Gain limits

Record station	Playback station	T_1, K	T_4, K	G_{MIN}, dB	G_{MAX}[a], dB
64-m	64-m	25	25	20	25
64-m	64-m	25	300[b]	31	25
64-m	64-m	300	25	9	14
64-m	64-m	300	300[b]	20	14
CTA 21	CTA 21	1000	1000	20	34
64-m	CTA 21	25	1000	36	50

[a]At 64-m stations $P_{T\,MAX} = -105$ dBm.

[b]Unacceptable combination.



OLR = OPEN LOOP RECEIVER
ARA = ANALOG RECORDING ASSEMBLY
UC = UPCONVERTER
CLR = CLOSED LOOP RECEIVER
SDA = SYMBOL DEMODULATOR ASSEMBLY
SSA = SYMBOL SYNCHRONIZER ASSEMBLY
TPA = TELEMETRY PROCESSOR ASSEMBLY

Fig. 1. Simplified diagram of telemetry recording and playback